Lecture: P1_Wk3_L3

AFM Components

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2012

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What's special about an AFM?

Optical and electron microscopy – "parallel" microscopy:

- Provide 2D lateral information
- The images appear "flat"
- Difficult to obtain information in the 3rd dimension

Scanning Probe Microscope – "proximal" microscopy:

- Image features extend in the **vertical** direction, out of the horizontal plane
- Local imaging at the nanoscale
- Allow for manipulation at the nanoscale
- Probe material properties at the nanoscale

The Atomic Force Microscope: Paper 001

VOLUME 56, NUMBER 9 PHYSICAL REVIEW LETTERS 3 MARCH 1986

Atomic Force Microscope

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IBM San Jose Research Laboratory, San Jose, California 95193
(Received 5 December 1985)

Control the tip-substrate force!

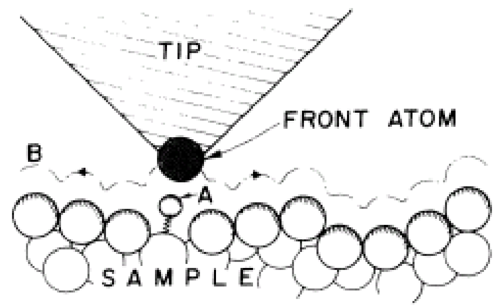
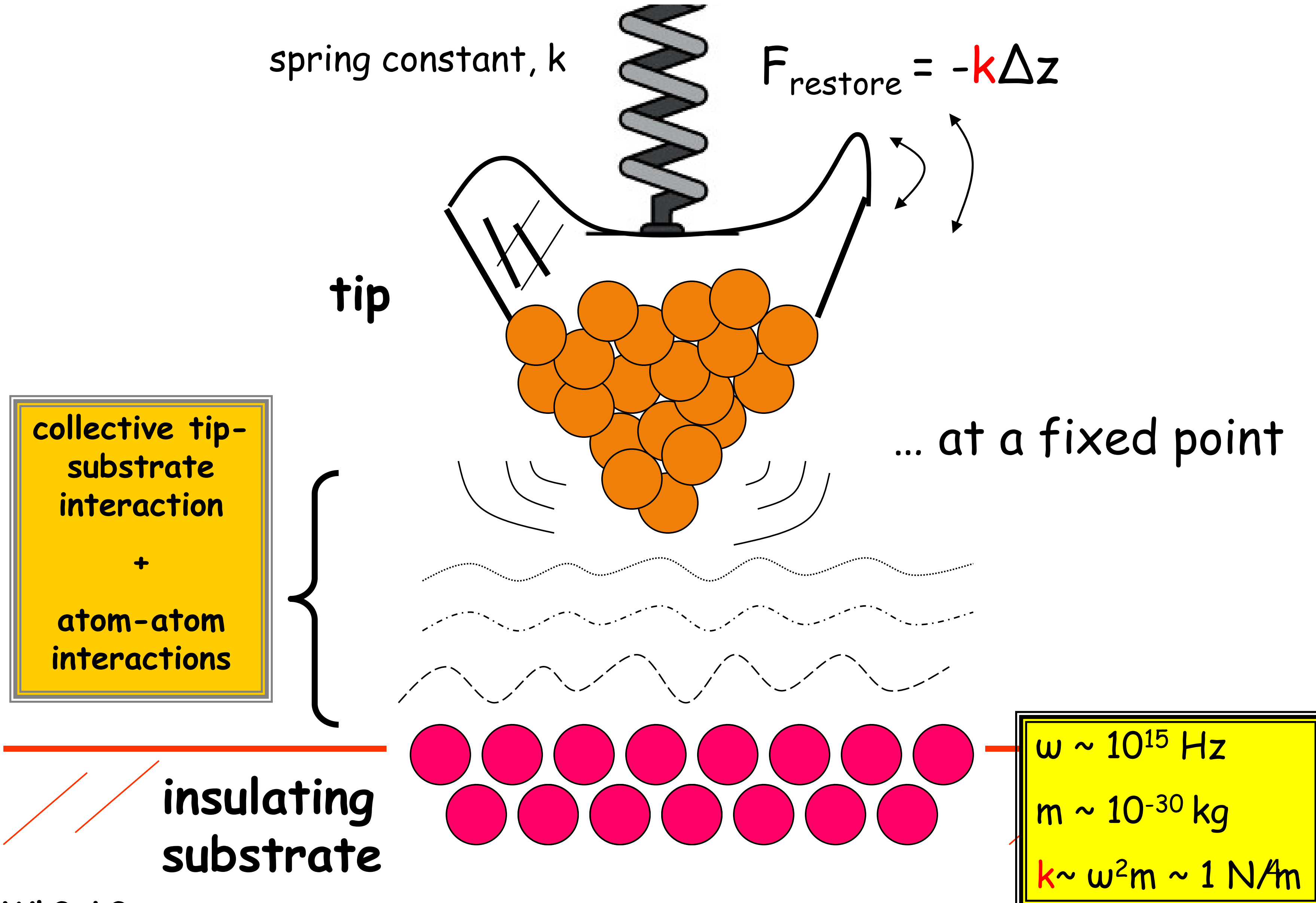
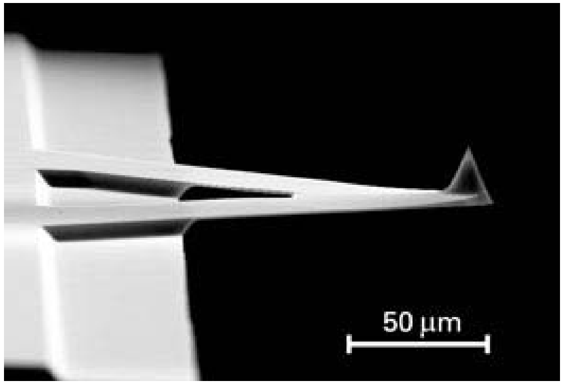


FIG. 1. Description of the principle operation of an STM as well as that of an AFM. The tip follows contour *B*, in one case to keep the tunneling current constant (STM) and in the other to maintain constant force between tip and sample (AFM, sample, and tip either insulating or conducting). The STM itself may probe forces when a periodic force on the adatom *A* varies its position in the gap and modulates the tunneling current in the STM. The force can come from an ac voltage on the tip, or from an externally applied magnetic field for adatoms with a magnetic moment.

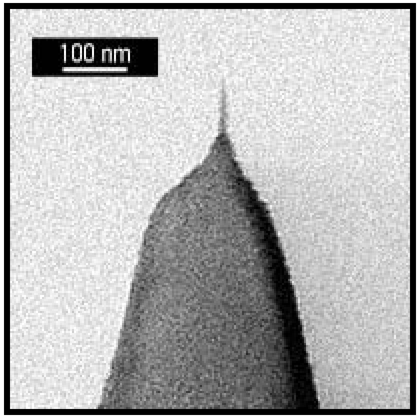
Why the AFM Works



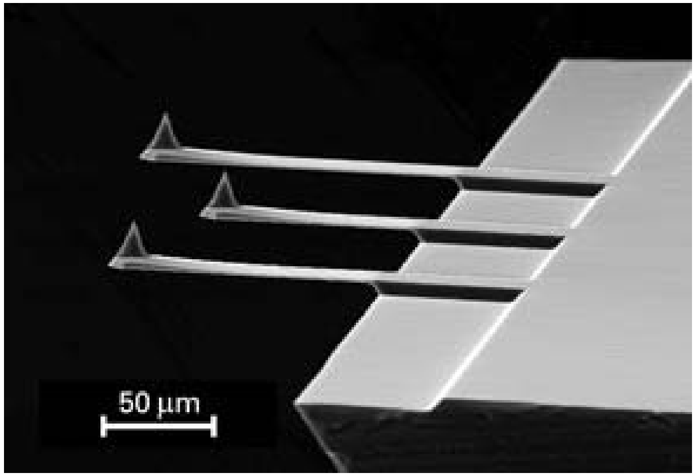
Commercially available microcantilever force transducers



www.spmtips.com



μmasch



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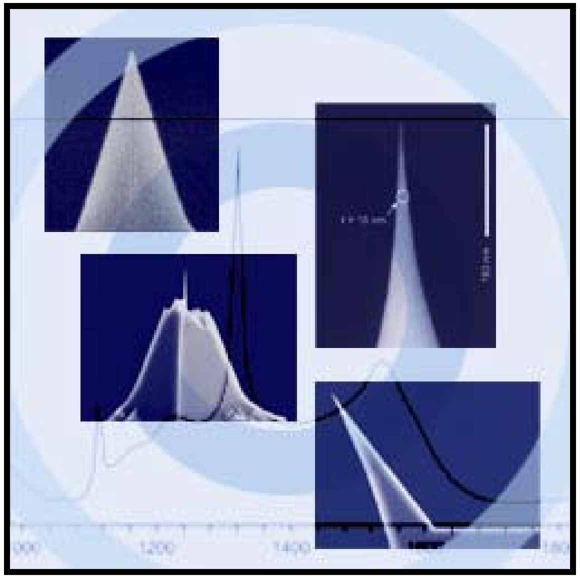
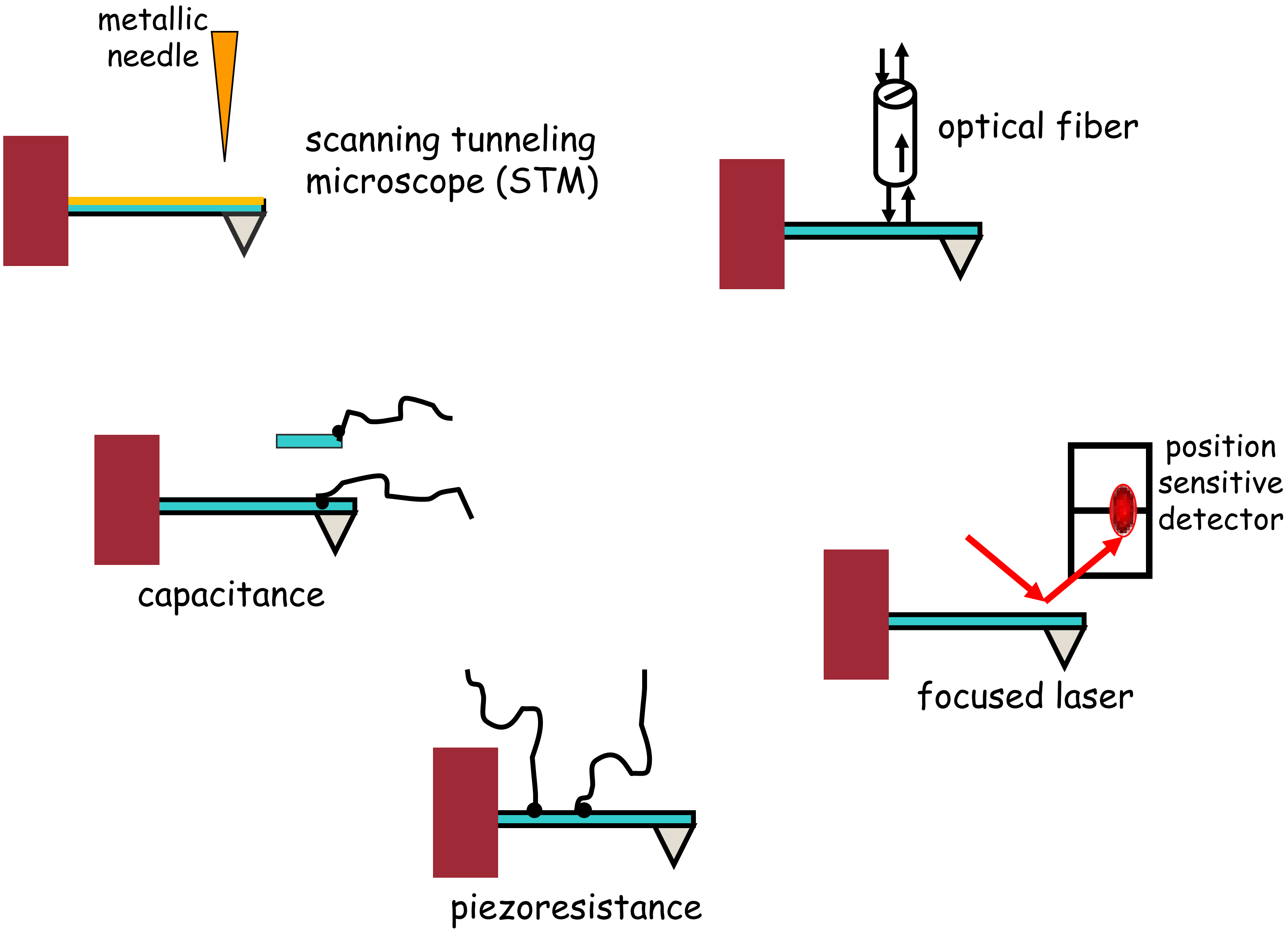


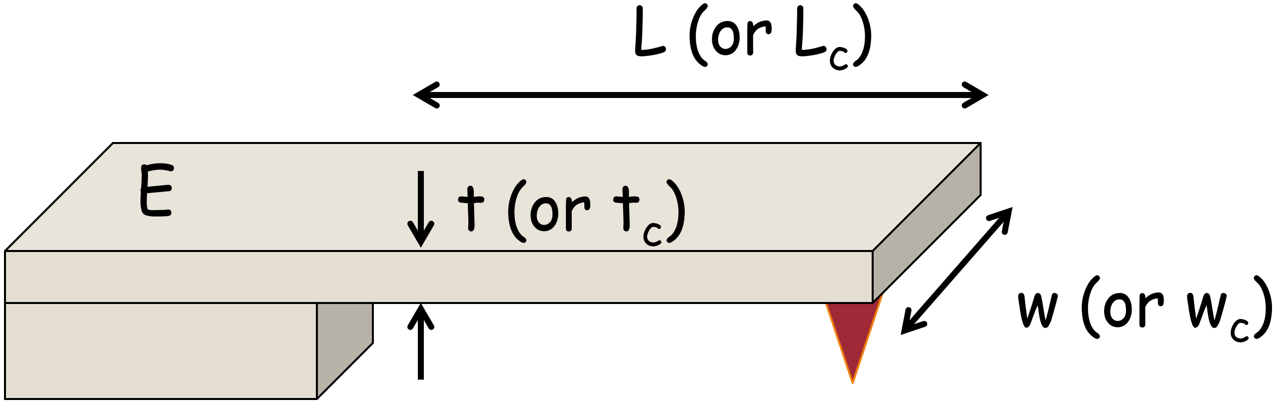
Typical use	k (N/m)	f_o (kHz)
Non-contact	10-100	100-300
Intermittent contact	1-10	20-100
Contact	0.1-1	1-50

www.nanosensors.com

Detecting Deflection

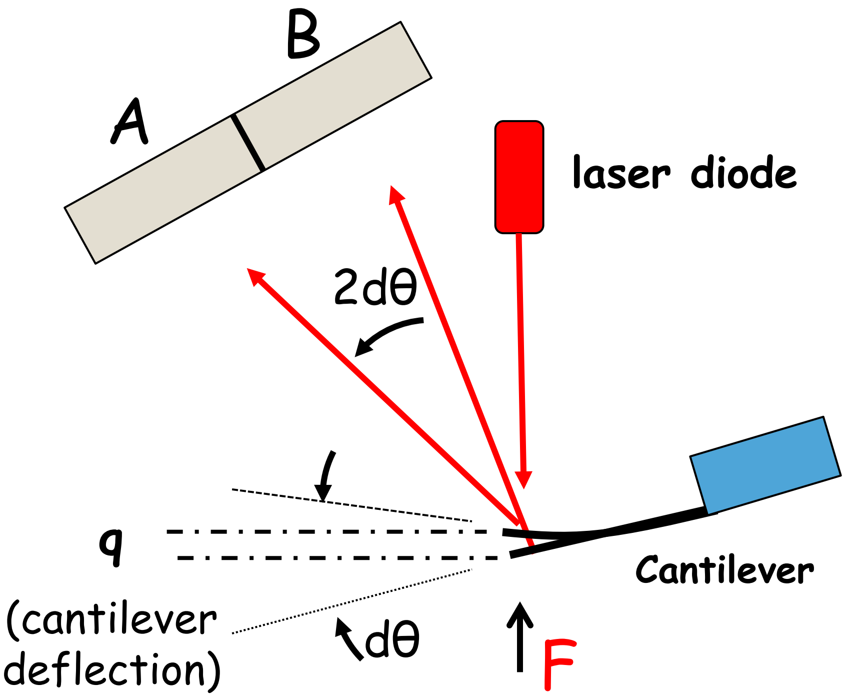


Notation: Cantilever Dimensions



Detecting Cantilever Deflection with a Segmented Photodiode

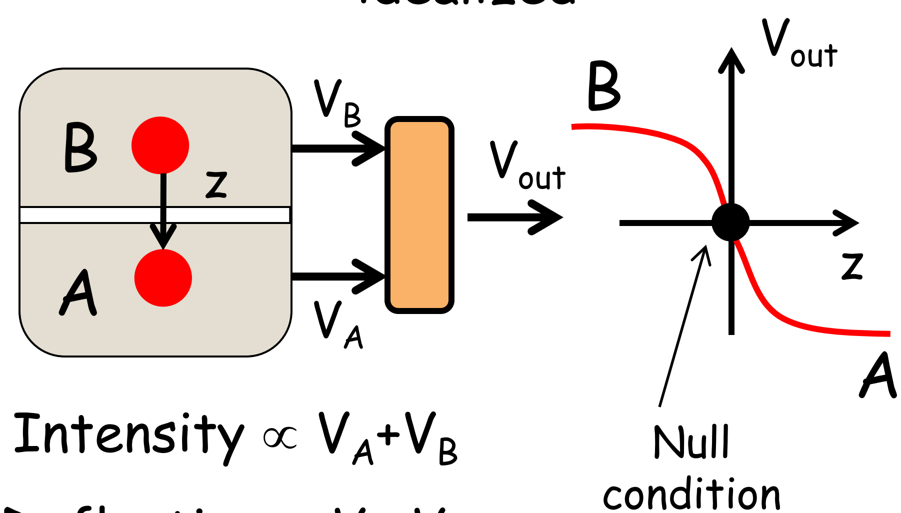
Cantilever response to force F



$$d\theta = \left(\frac{6L^2}{Ewt^3}\right) F$$

$$\text{tip displacement} \equiv q = \left(\frac{4L^3}{Ewt^3}\right) F$$

Segmented Photodetector (PSD) - idealized -



Intensity $\propto V_A + V_B$

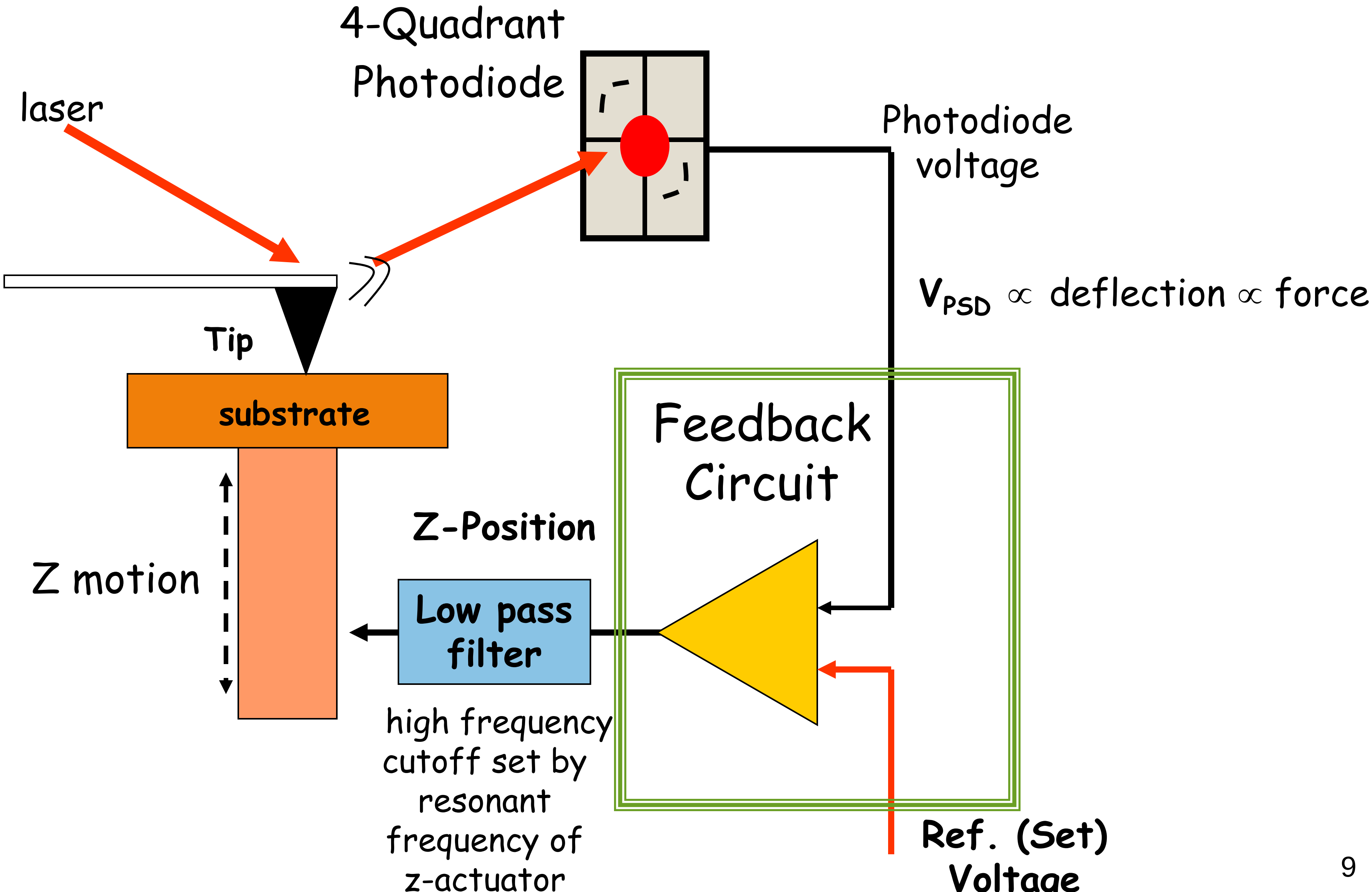
Deflection $\propto V_B - V_A$

$$V_{out} = \frac{V_B - V_A}{V_A + V_B} \propto q$$

$$V_{out} = S \bullet q$$

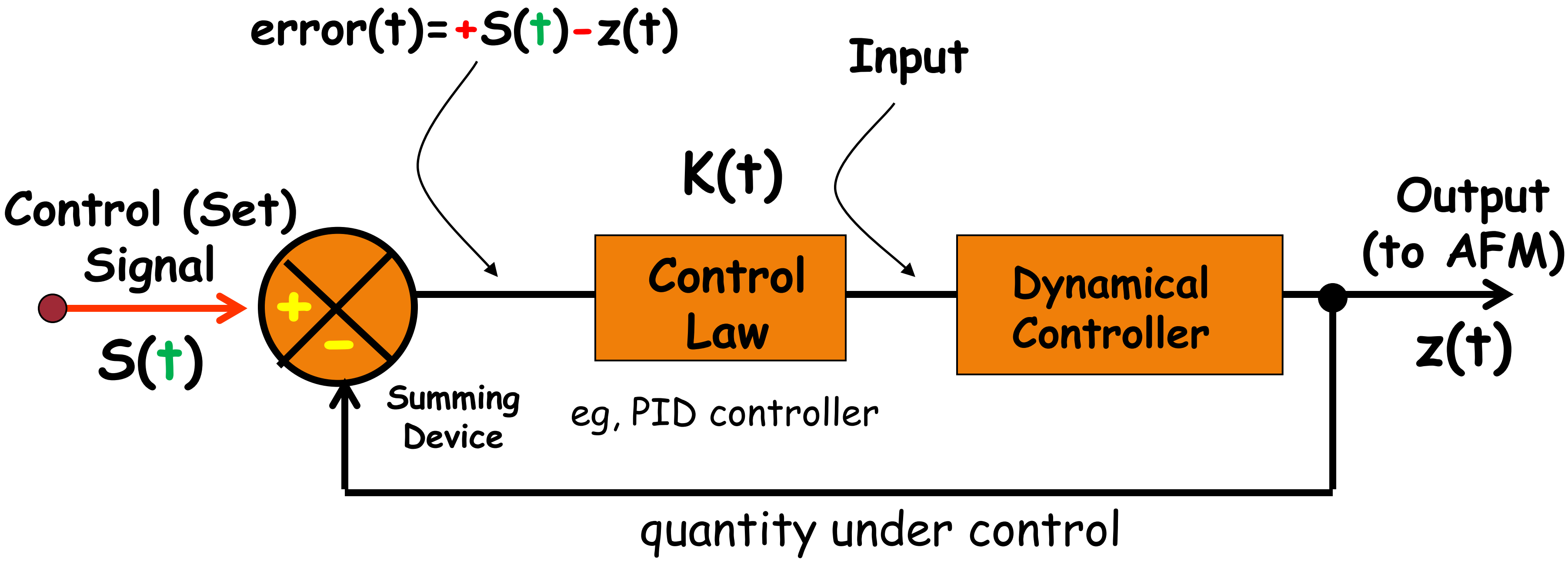
Cantilever Displacement vs. Cantilever Rotation: Which is more Important? – see Appendix

Maintaining a constant force



Principle of Feedback: controlled modification of a dynamical system

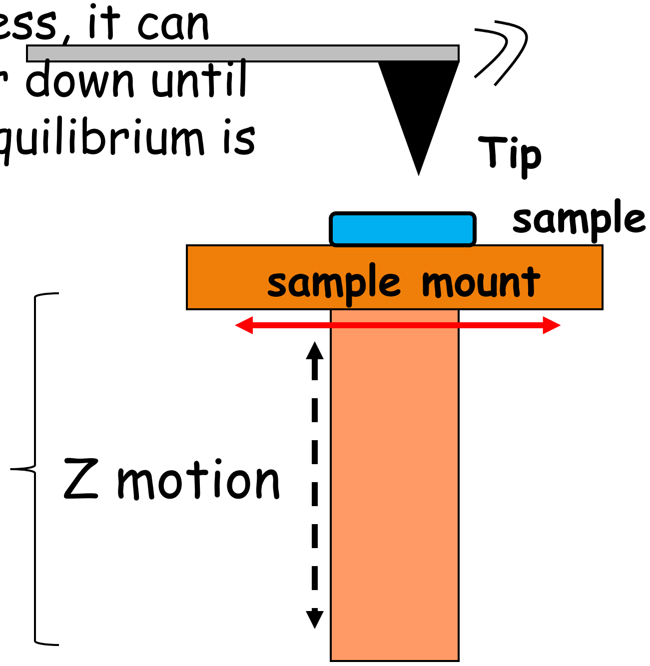
Goal: Make z(t) follow S(t) as closely as possible



- K(t) tries to minimize error(t)
- Negative feedback!

Need to Minimize Thermal Drift
(drfit parallel and/or perpendicular to tip)

If cantilever beam is under stress, it can bend up or down until thermal equilibrium is reached



typically,

L~ 0.01 – 0.05 m

$$\Delta L = \alpha L \Delta T$$

$$\frac{dL}{dt} = \alpha L \frac{dT}{dt}$$

$$= \alpha (0.01\,m)(1^\circ C/min) \approx 10 - 100\ nm/min$$

Material	α (°C⁻¹)
Al	23 x10^{-6}
steel	~12 x10^{-6}
Au	14 x10^{-6}
glass	3-8 x10^{-6}
Invar	1.2 x 10^{-6}

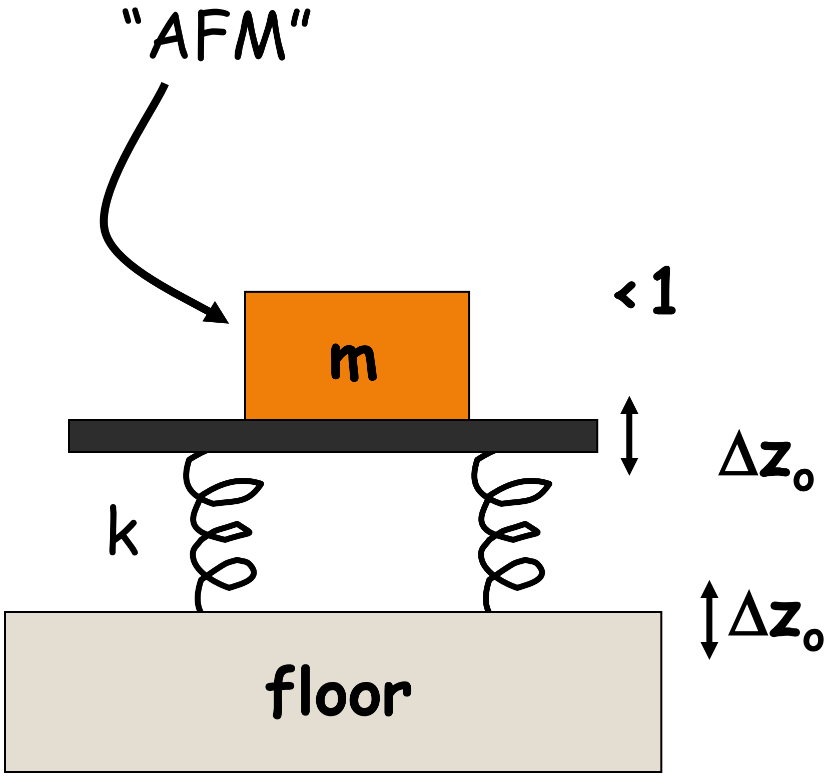
Reasons for ΔT:

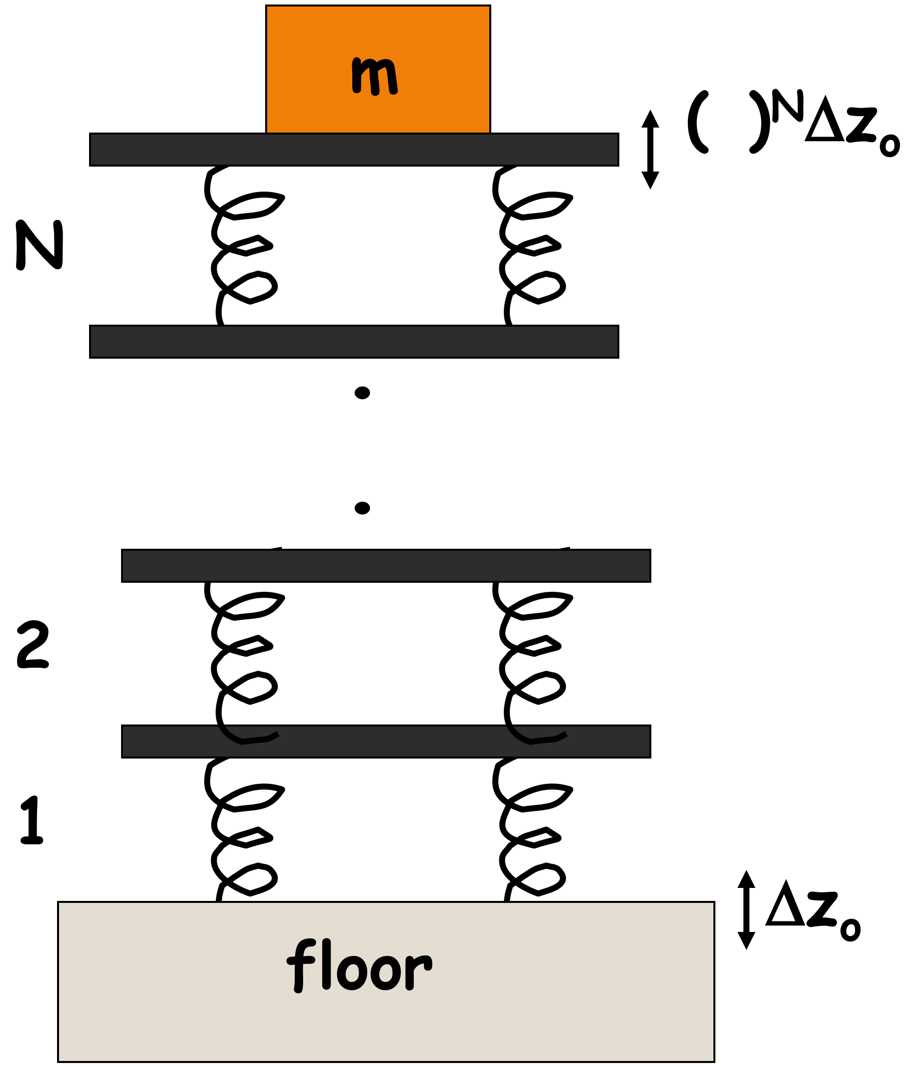
- laser illumination
- heat from electronics

(ΔT~5K) (for the two items above)

- sample mounting
- use of materials with low thermal conductivity
- external illumination by incandescent lamp

Reducing Floor Vibrations



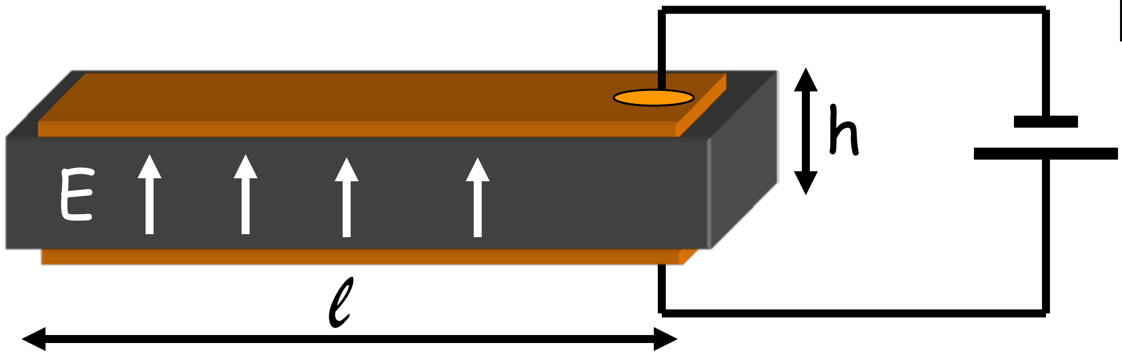


Internal resonance frequency of AFM components becomes important

Achieving Vibrationless Motion at the Nanoscale

$$\Delta \ell = d_{31} \frac{\ell}{h} V_o$$

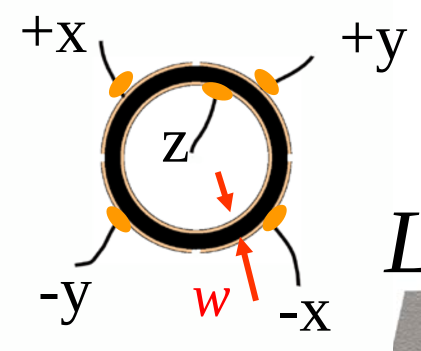
Piezoelectric Bar

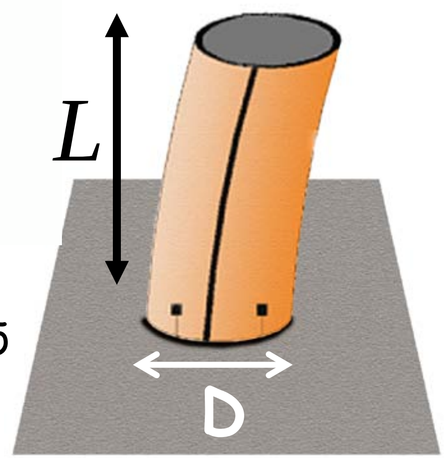


With d_{31} ~ 10-100 pm/V,

typically, $\Delta \ell$ ~ 0.5 nm/V

Quadranted Piezoelectric Tube: Binnig and Smith, RSI **58**, 1688 (1986)



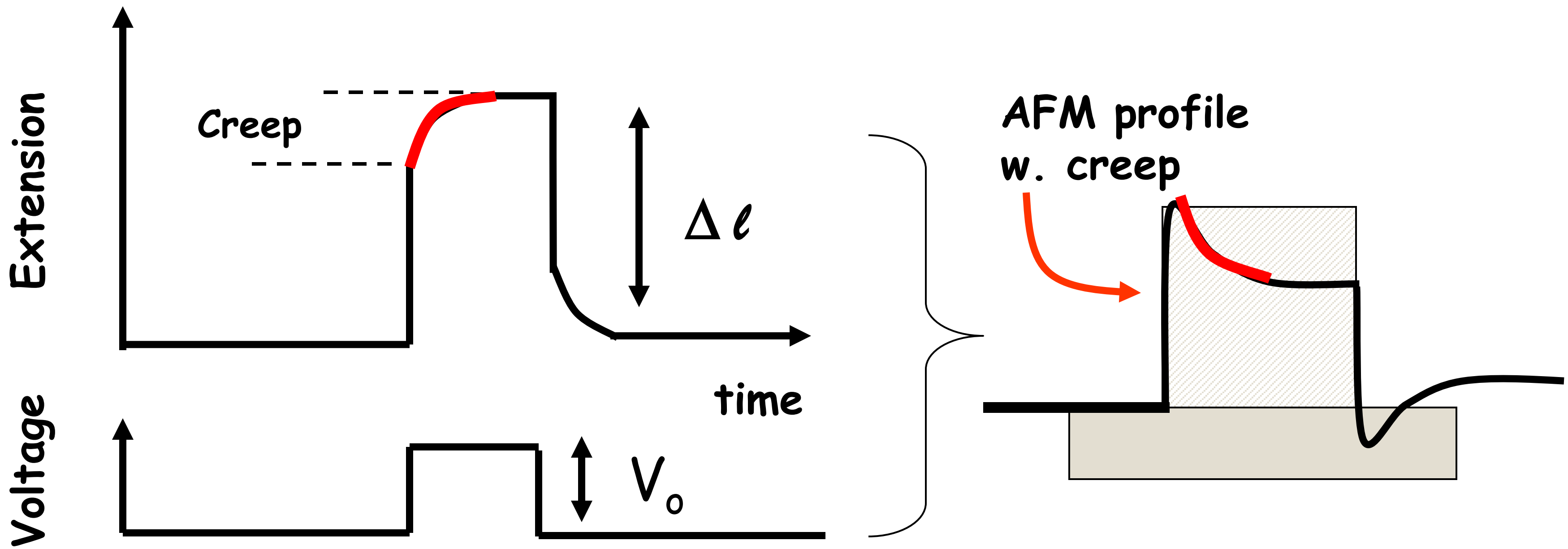


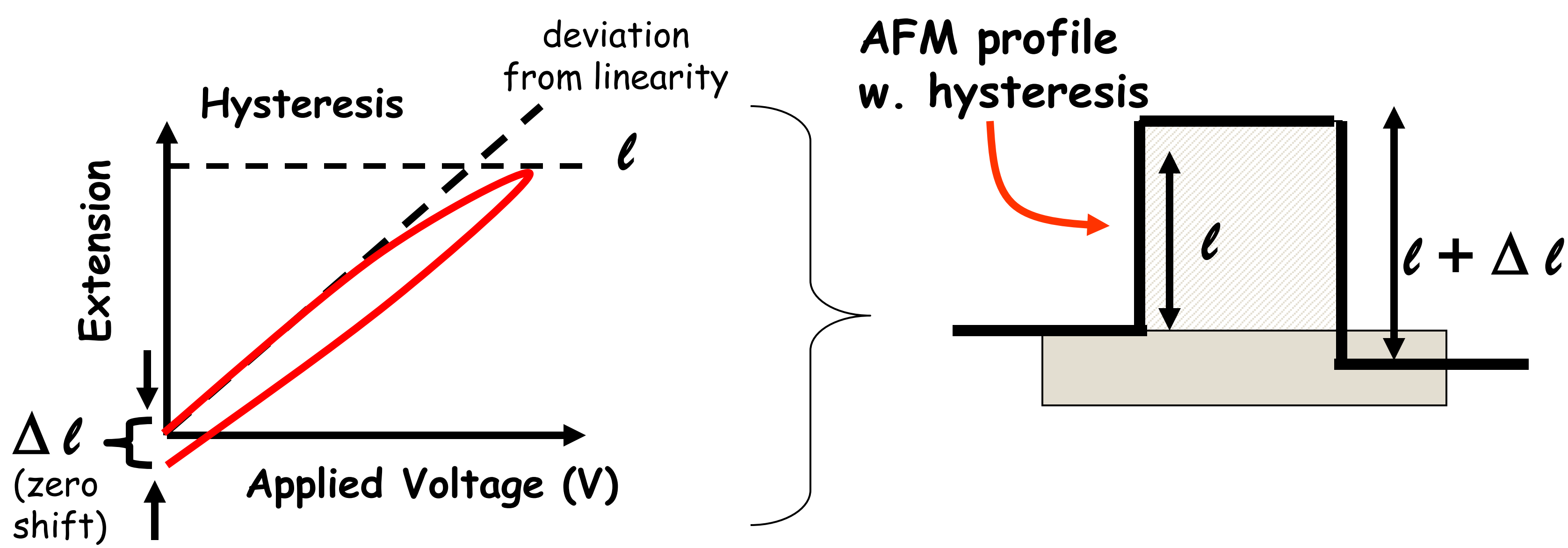
resonant frequency:
~few hundred Hz to ~25 KHz - limits scan speed

$$\Delta z = L \frac{V_o}{w} d_{31}$$

$$\Delta x \simeq \Delta y = \frac{2\sqrt{2}}{\pi D} \frac{V_o}{w} L^2 d_{31}$$

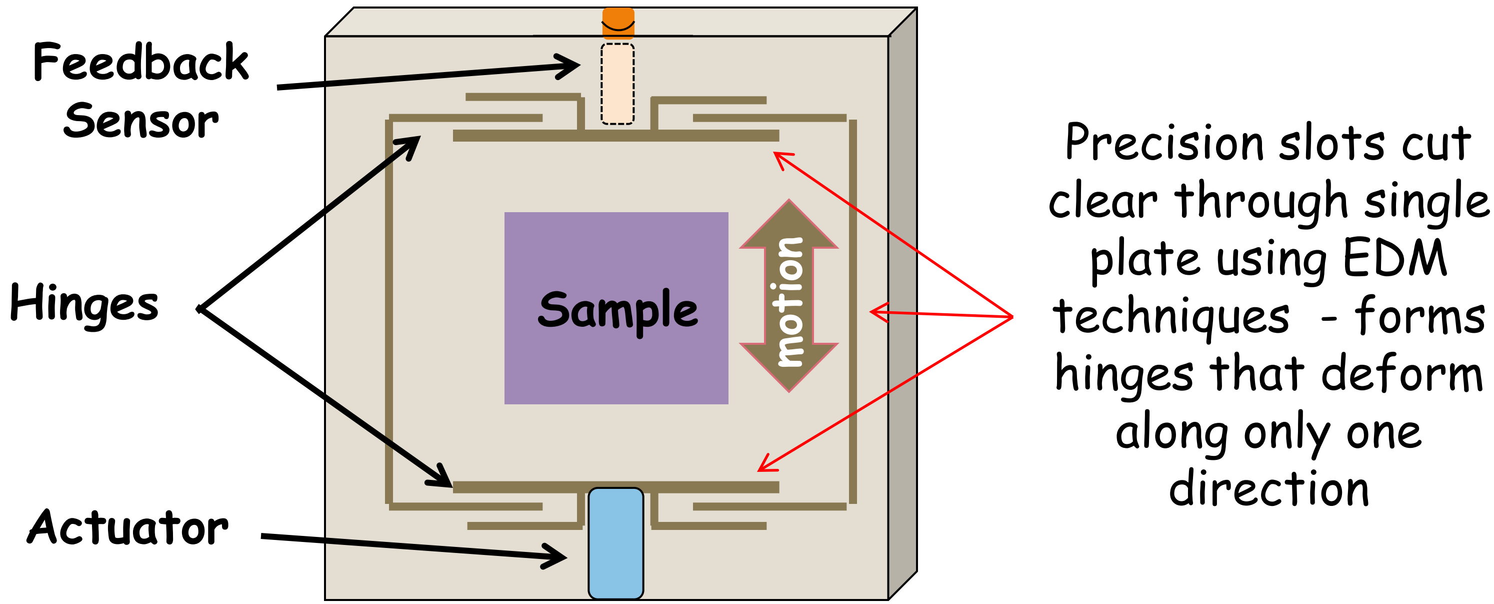
Piezoelectric Creep and Hysteresis





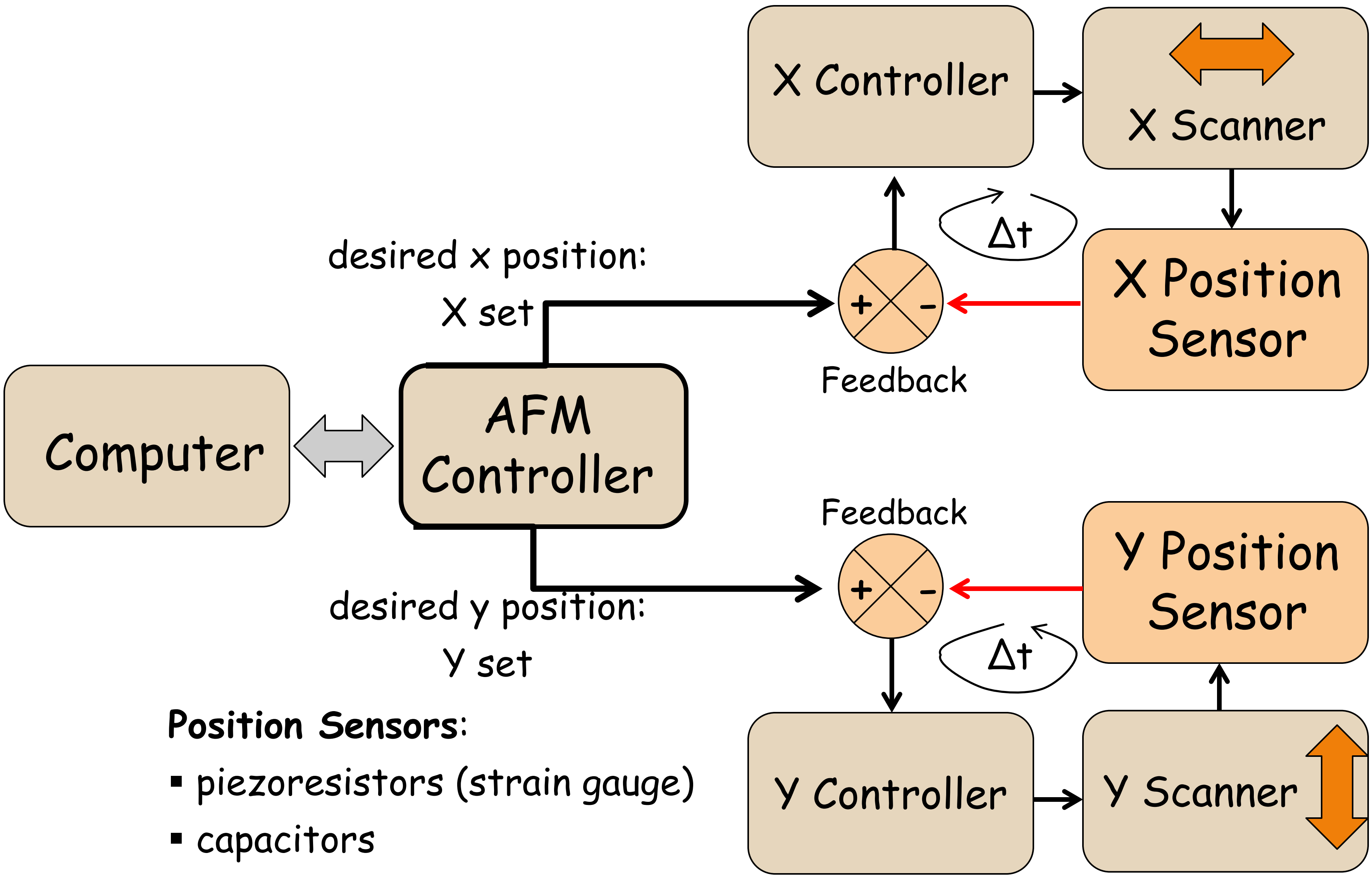
Flexure Scanners/Nanopositioning Stages

Flexure based stages have zero mechanical friction and the flexures restrict the motion of each axis to a single direction, effectively producing a pure, 1-dimensional translation.



- max. scan ranges from ~0.5 μm to ~500 μm, depending on actuator
- resonant frequency: ~few hundred Hz to 1 KHz - limits scan speed
- minimal out-of-plane curvature over the entire scan range: out- of-plane movement of only a few nanometers
- accurate and repeatable positioning
- linear positioning independent of scan rate, scan range, and scanner offset

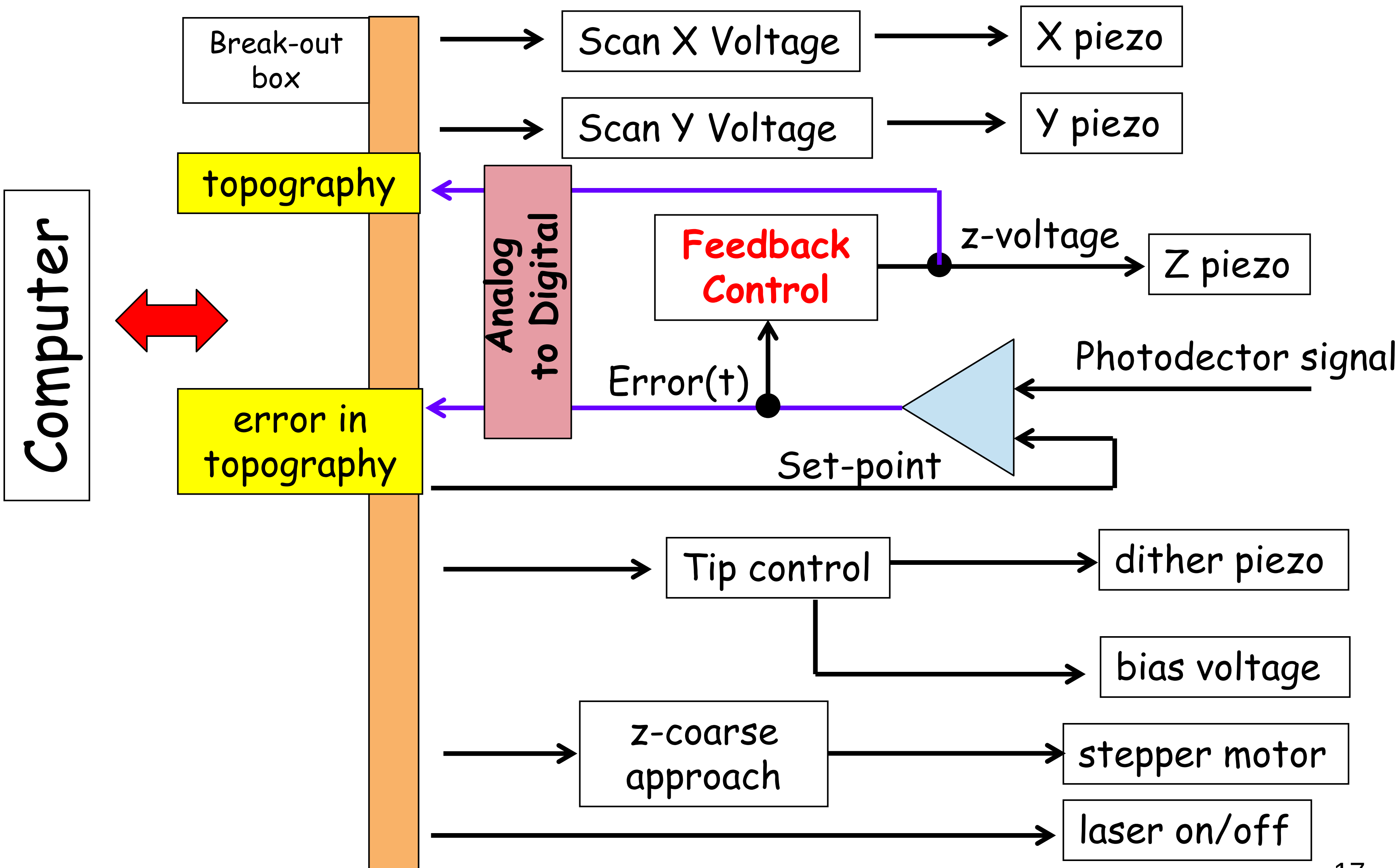
Closed Loop Scanners – Linearized Scanning



Position Sensors:

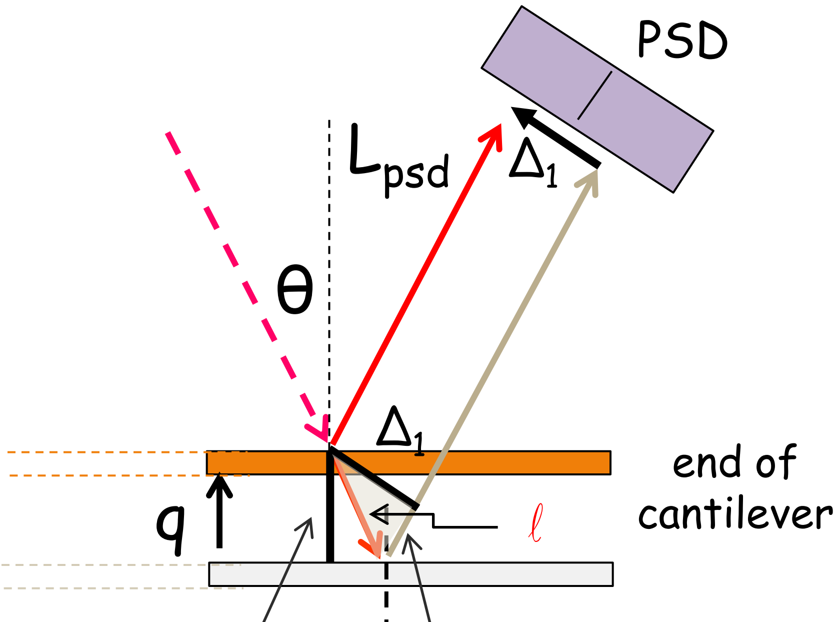
- piezoresistors (strain gauge)
- capacitors
- inductors (LVDT)

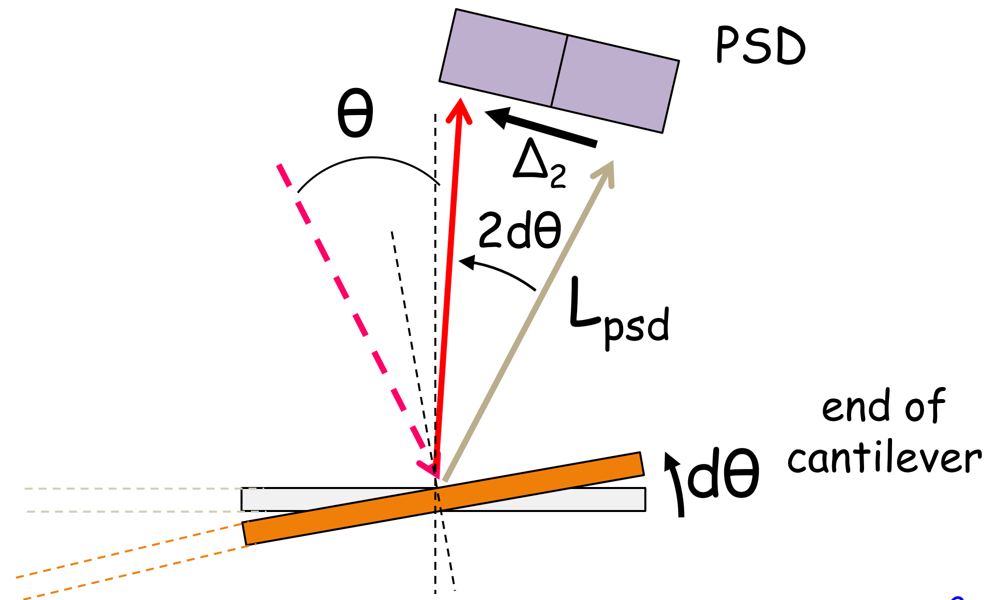
Important Electrical Signals



Up Next: AFM Calibration

Appendix: Cantilever Displacement vs. Cantilever Rotation: Which is more Important?





$$\cos\theta = \frac{q}{\ell}$$

$$\sin 2\theta = \frac{\Delta_1}{\ell}$$

$$\Delta_1 = \ell \sin 2\theta = \frac{q}{\cos\theta}\sin 2\theta = 2q\sin\theta$$

$$= 2\frac{4L^3}{Ewt^3}F\sin\theta$$

$$\Delta_2 = 2L_{psd}\,d\theta = 2L_{psd}\frac{6L^2}{Ewt^3}F$$

$$\frac{\Delta_2}{\Delta_1} = \frac{12}{8}\frac{L_{psd}}{L}\frac{1}{\sin\theta}$$

$$L_{psd} = 2\text{cm}$$

$$L = 200\,\mu\text{m}$$

$$\theta \approx 30^0$$

$$\Delta_2 \approx 300\,\Delta_1$$

Motion across PSD due primarily to **cantilever rotation**